Variations of Kuroshio Intrusion and Internal Waves at Southern East China Sea

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Award Number: N00014-07-1-0245

LONG-TERM GOALS

My long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes- i.e., internal tides, inertial waves, NLIWs, and turbulence mixing- in the ocean and thereby help develop improved parameterizations of mixing for ocean models. Mixing within the stratified ocean is a particular focus as the complex interplay of internal waves from a variety of sources and turbulence makes this a current locus of uncertainty. For this proposal, my broad focus is on small-scale processes (NLIWs and inertial waves), internal tides, and cold water intrusions generated as the Kuroshio and barotropic tides interact with the continental shelf of the East China Sea (ECS) and with one prominent submarine ridge (I-Lan Ridge) (Fig. 1). These small scale processes modulate the temporal, horizontal and vertical spatial structures of temperature in the ocean, and therefore may significantly modify oceanic acoustics properties and introduce uncertainty on sonar performance and acoustic propagation.

OBJECTIVES

The primary objectives of this observational program are 1) to quantify the Kuroshio intrusion and its migration and the dynamics on the southern East China Sea (SECS), 2) to identify the generation mechanisms of the Cold Dome often found on the SECS, 3) to quantify the internal tidal energy flux and budgets on the SECS and study the effects of the Kuroshio front on the internal tidal energy flux, 4) to quantify NLIWs and provide statistical properties of NLIWs on the SECS , and 5) to provide our results to acoustic groups to assess the uncertainty in the acoustic prediction. Our ultimate goal is to collaborate with acousticians to identify oceanic processes that alter acoustic properties. Detailed properties, mechanisms, and dynamics of these oceanic processes will help quantify and assess the uncertainty in the acoustic prediction.

APPROACH

A field observational program, as a part of an integrated observational program, is proposed (Figs. 1 and 2). Two components of the observational program are planned. For the extended observational program, 6-months across the southwest and northeast monsoons, I propose to deploy an array of six 75-kHz Long Rangers with thermistor chains; two in the Mien-Hua Canyon and four on the continental slope between the North Mien-Hua Canyon and Mien-Hua Canyon. These observations will be used to quantify the Kuroshio intrusion and migration, internal tidal energy and energy flux, NLIWs, and the Cold Dome. For the ~1-month intensive observational program on the continental shelf, overlapping with the extended observational program, I propose to tow a CTD chain between six ADCP moorings on the continental shelf to be deployed by U.S. and Taiwanese colleagues.

WORK COMPLETED

- In the past year, I attended three ONR workshops, discussed and helped defined the integrated observational program.
- In July, 2007, a Long Ranger ADCP bottom-mounted mooring was deployed on the slope of Mien-Hua Canyon (red bullet in Fig. 2). The mooring will be recovered in November 2007.
- I performed preliminary analysis of historical CTD data and mooring observations to quantify effects of oceanic processes on the sound speed (Figs. 3-7).

RESULTS

In July 2007, I deployed a bottom-mounted Long Ranger ADCP on the slope of the Mien-Hua Canyon at 600-m depth (Fig. 2). The location was chosen where numerical models suggest strong internal tides (Jan, personal communication) and possible Kuroshio intrusion (Lermusiaux, personal communication). This ADCP mooring will be recovered in November 2007 and will provide useful observations of internal tides, Kuroshio intrusion, and NLIWs in Mien-Hua Canyon.

Historical CTD data collected by the National Center for Ocean Research (NCOR) between 1985 and 2002 are used to compute the fluctuations of sound speed in different regions along the Kuroshio path and across the continental shelf and slope (Fig. 3).

Standard deviations of sound speeds averaged in the areas north and south of I-Lan ridge are shown in Fig. 4. A band of strong standard deviation extending from the surface to ~200 m in the north of I-Lan ridge might represent the effect of the migration of the Kuroshio front. A deeper band near 400-m depth may be associated with the base of the Kuroshio. The strong sound speed anomaly is also found in the upper ocean, likely associated with the change of the thermal structure in the surface mixed layer.

The Kuroshio interaction with the continental slope and shelf could lead to large fluctuations of sound speed (Fig. 5). A ~100-km horizontal band of strong sound speed anomaly is found emanating from the continental shelf break of SECS. Small patches of large sound speed anomaly on the continental shelf may be associated with NLIWs.

Above Mien-Hua Canyon and North Mien-Hua Canyon, the largest sound speed anomaly is found with the maximum standard deviation about 10 m s^{-1} (Fig. 6). We attribute this anomaly to NLIWs often found in satellite images.

The sound speed anomaly induced by oceanic processes in the SECS is summarized in Fig. 7. The Kuroshio interaction with the continental shelf and slope introduce the sound speed anomaly (standard deviation) about 5 m s^{-1} which decays with depth. Such sound speed anomaly has the horizontal scale of O(10s-100 km). NLIWs on the continental shelf may introduce the sound speed anomaly as large as 10 m s^{-1} with the horizontal scale O (1km) in a short time scale O(10s min). In comparison, NLIWs found in the Philippine Sea generate much weaker sound speed anomaly. Internal tides also cause sound speed anomaly as large as 5 m s^{-1} centering at the thermocline.

IMPACT/APPLICATION

Our preliminary analysis concludes that strong sound speed anomalies are induced by NLIWs, internal tides, and processes associated with the Kuroshio interaction with the continental slope and shelf. Such sound speed anomalies have the temporal and spatial scales and characteristics associated with the corresponding oceanic processes. To quantify, predict, and exploit the uncertainty of the acoustic propagation and sonar performance, we need to understand the dynamics of these responsible oceanic processes and their effects on the sound speed. This is the main goal of the proposed experiment.

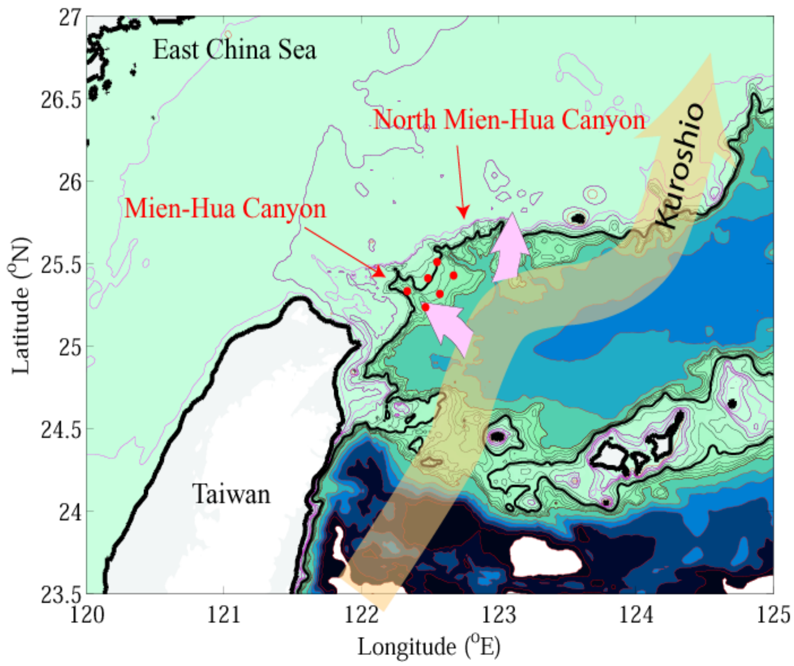

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Figure 1: Bathymetry map of the Southern East China Sea. The contour interval is 100 m between 0 and 1000-m depth and is 500m for depth greater than 1000 m. Thick solid curves indicate 0 and 500-m isobaths. The Kuroshio main path and intrusion paths are illustrated. Six dots mark the location of the proposed ADCP moorings.

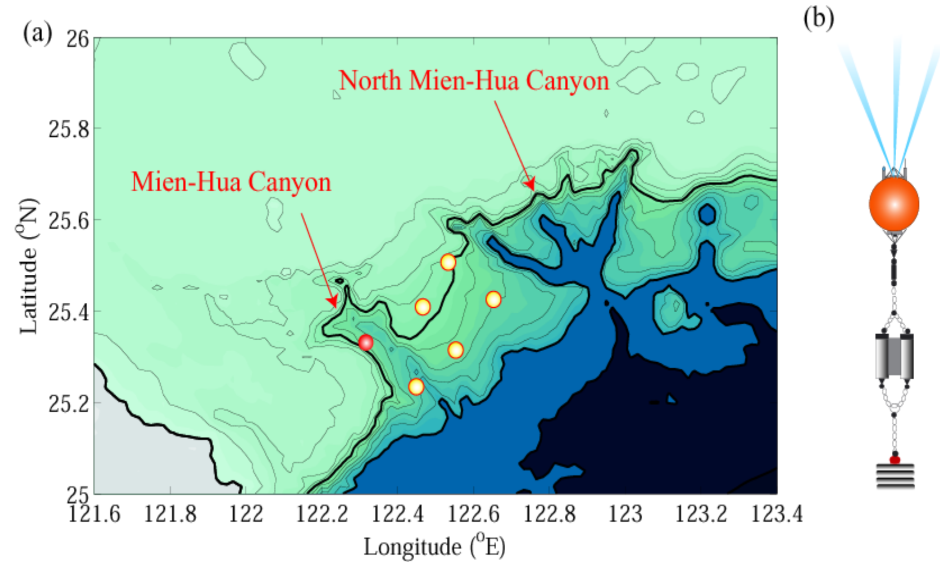

Figure 2: (a) bathymetry map of the southern East China Sea, and (b) configuration of bottom mounted ADCP. Six bullets in panel (a) indicate the positions of the proposed ADCP moorings. The red bullet indicates the position of ADCP deployed in July 2007.

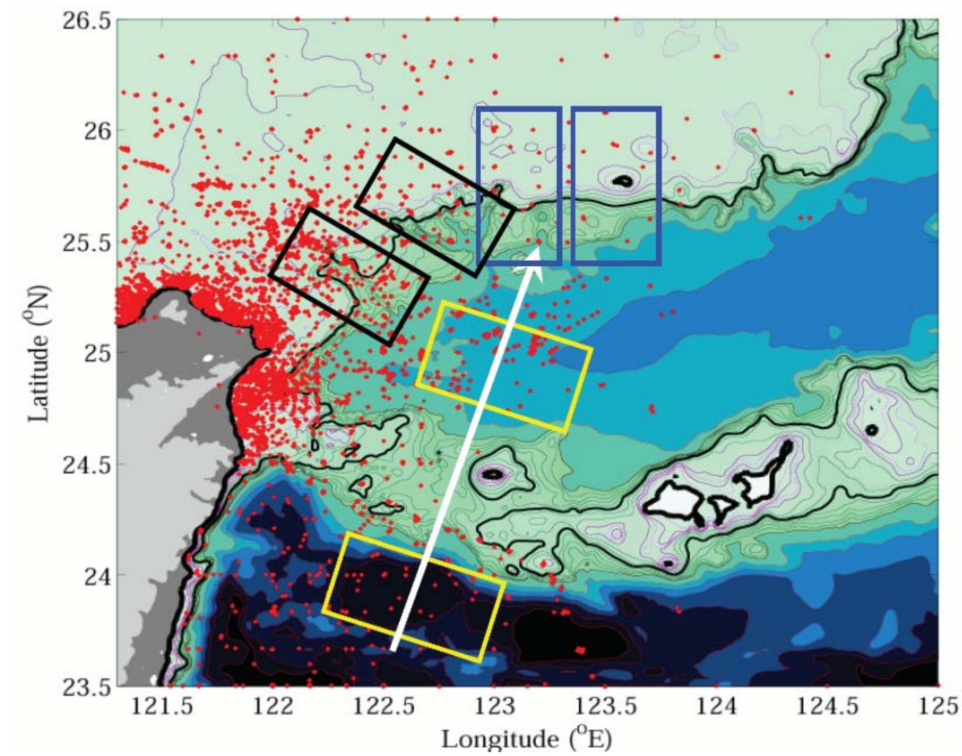

Figure 3: Locations of historical CTD (red dots) and area sections where CTD data are used for computing the sound speed anomaly.

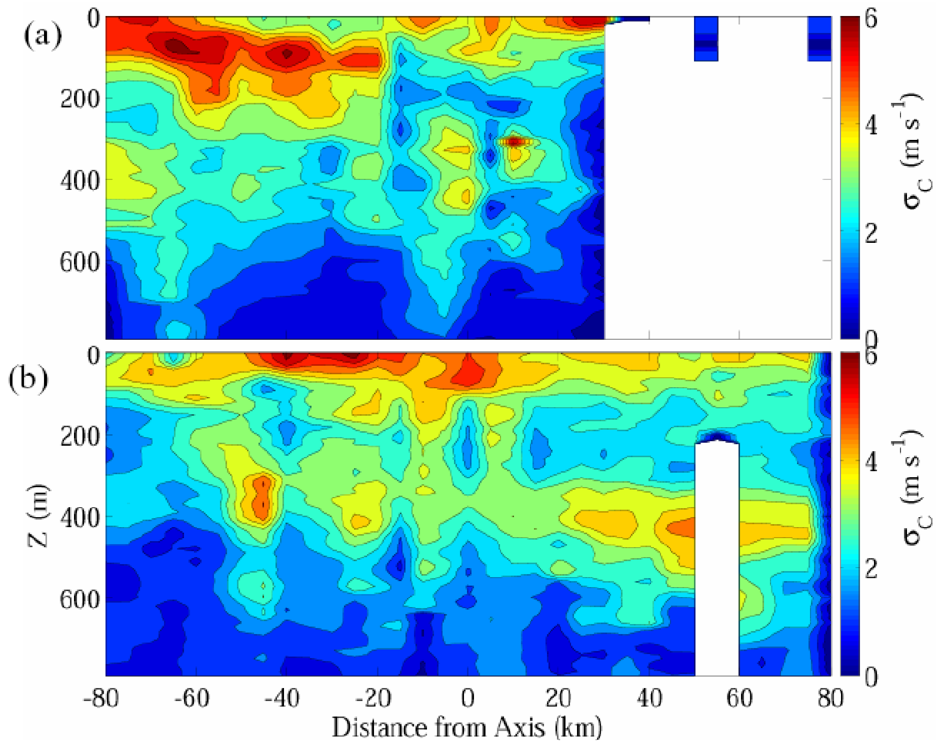

Figure 4: Standard deviations of sound speed averaged over sections at (a) north of I-Lan Ridge (the top yellow box in Figure 3), and (b) south of I-Lan Ridge (the bottom yellow box in Figure 3).

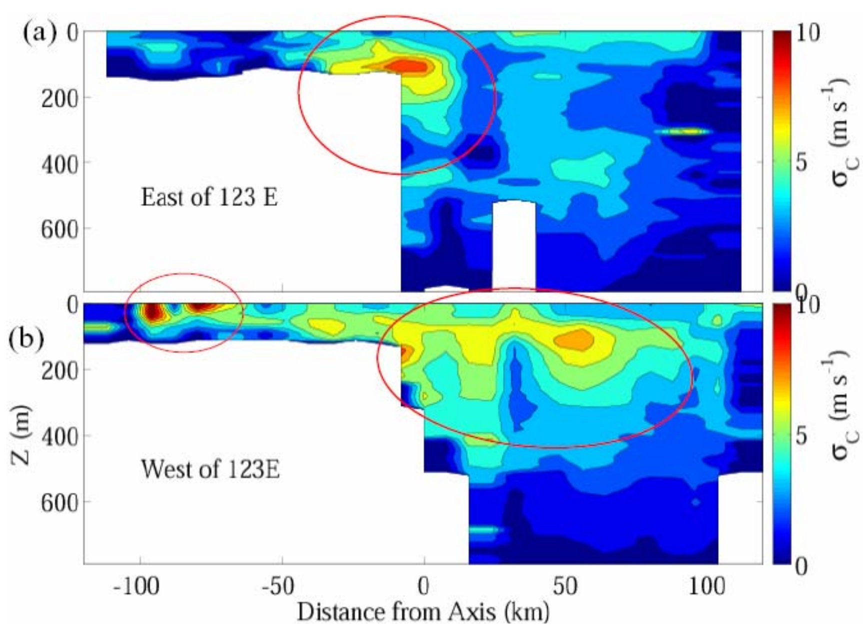

Figure 5: Standard deviations of sound speed averaged over sections across the continental slope and the continental shelf on the main path of Kuroshio at (a) east of 123 ^{o}E (the right blue box in Figure 3) and (b) west of 123 ^{o}E (the left blue box in Figure 3).

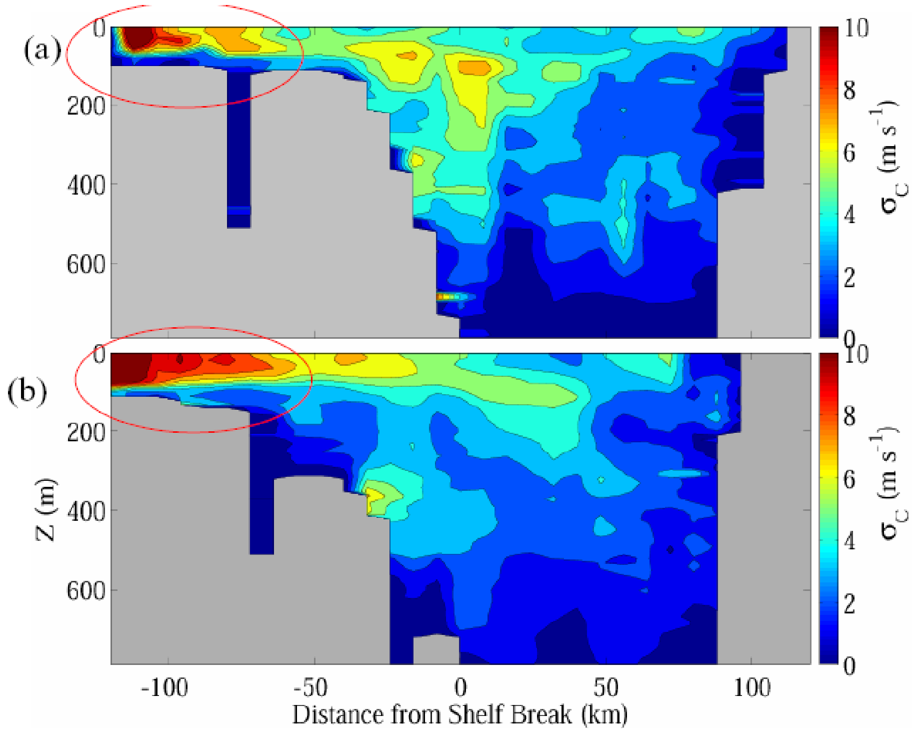

Figure 6: Standard deviations of sound speeds averaged over sections across the continental slope and the continental shelf on possible intrusion paths of the Kuroshio centering around (a) North Mien-Hua Canyon (the top black box in Figure 3) and (b) Mien-Huan Canyon (the bottom black box in Figure 3).

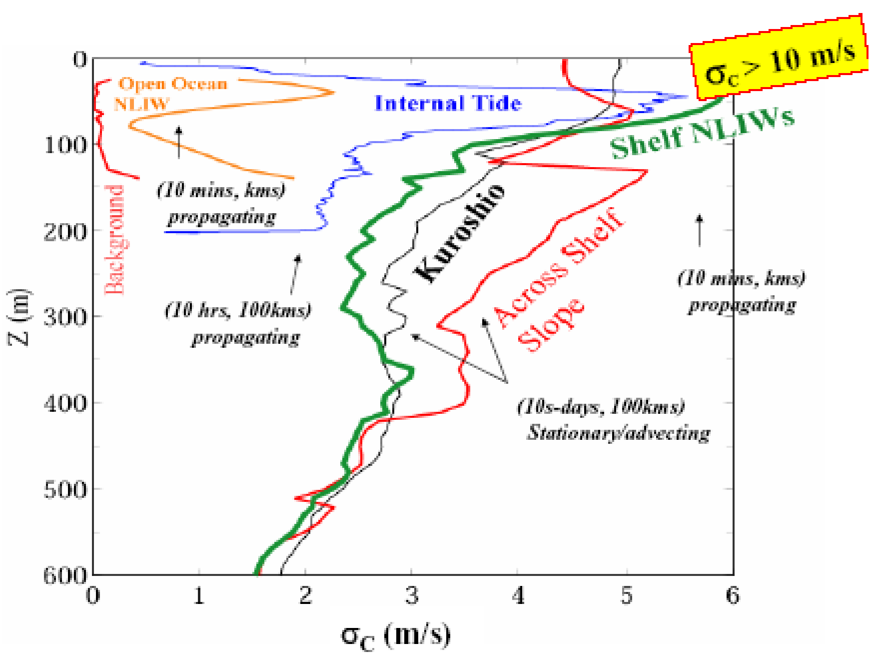

Figure 7: Summary of the sound speed anomaly introduced by primary oceanic processes along the Kuroshio path near the southern East China Sea. Typical temporal and spatial scales and characteristics of oceanic processes are labeled. The standard deviation of sound speed associated with NLIWs on the continental slope exceeding 10 m s^{-1} is highlighted.